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WIDE-SLOTTED PRINTED SLOTLINE RADIATOR

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Abastract: *This paper summarizes an investigation of radiation from the slotline made on a thin low permittivity substrate. The slot radiates the space leaky wave of the 1st order. The dispersion characteristic of this wave is presented. Two versions of the antenna were designed, optimized and fabricated. The wide slot is fed by the microstrip patch in the first design, and by the CPW patch in the second design. The measured and calculated return loss and also the radiation patterns compare well for both the first and the second antenna.*

Introduction

Planar antennas have been of great interest to researchers and engineers in recent decades, and have a wide spectrum of applications. Their low weight and easy manufacture has resulted in cheap mass production. Due to their low profile they save space and can therefore be located on any surface. Planar antennas can be directly integrated with their feeding circuits. Basically there are two kinds of planar antennas [1,2]. The first kind utilizes the standing wave in the resonant structure radiating power. The second antenna type radiates power by the wave travelling along a proper transmission line. The former usually operates in a narrow frequency band, while the latter can radiate in a wide frequency band.

This paper deals with slotline leaky wave antennas belonging to the traveling wave antennas group. The slotline antenna utilizing the leakage effect was first presented in [3]. We investigated the space leaky waves on the wide-slotted slotline in [4] and showed in [5] that this line radiates due to the excitation of the first space leaky wave. Based on that knowledge we designed two slotline leaky wave antennas differing mainly in feeder shape, optimized by the Zeland IE3D solver. The properties of the feeder reduce the antenna operation frequency band in comparison with the band in which the leaky wave can be effectively excited. Measured and calculated antenna return loss and also radiation patterns compare well.

Physical background – leaky waves on the slotline

Surface leaky waves radiating power into the substrate and space leaky waves radiating power into space can be excited under certain circumstances on all kinds of planar and uniplanar open transmission lines. Surface leaky waves cause losses and crosstalk and therefore prevent proper operation of the line. Space leaky waves are exploited in leaky wave antennas for radiating power. In order to design a printed slotline leaky wave antenna it is necessary to understand the behaviour of space leaky waves on the slotline with a wide slot fabricated on a low permittivity substrate. The cross-section of the line is drawn in Fig. 1. We determined the dispersion characteristics of the modes by the method of moments in the spectral domain. The frequency dependence of the complex propagation constants, normalized to k_0, of waves propagating on the slotline with the slot 60 mm wide on the substrate 1.2 mm thick with permittivity 2.6 are plotted in Fig. 2. They belong to the dominant bound wave with even symmetry of the transversal component of the electric field within the slot, the 1st higher order bound wave and the 1st space leaky waves with odd symmetry. However we can find an infinite number of branches of the dispersion characteristics of the space leaky waves of different orders [4].

The space leaky wave is physical at frequencies when its phase constant is lower than k_0. That is between 1.5 and 4.5.GHz for the slotline investigated here, see Fig. 2. The leakage constant of this wave grows with decreasing frequency. Its high value does not mean high radiation efficiency, since the power is mostly radiated into the substrate. The applicable frequency band of our slotline antenna therefore spans approximately from 2.25 to 4.5 GHz, Fig. 2.

Design of the antenna and its feeder

The antenna feeding network must provide the excitation of the space leaky wave of the first order in the desired frequency band, therefore its optimization is the crucial point of the antenna design. Two antenna feeders were designed by the Zeland IE3D simulator, on the substrate 1.2 mm thick with permittivity 2.6, then fabricated and

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tested. The slotwidth affects the leakage constant, therefore the value 60 mm was chosen in order to keep a low leakage constant. The length of the slotline 300 mm was determined by the distance at which the amplitude of the 1st space leaky wave decreased to 1% of its initial magnitude at 3 GHz.

The first antenna was fed by the microstrip patch placed along the slotline axis on the opposite side of the substrate, Fig. 3. The slotline was terminated by the narrow slotline on which the 1st space leaky wave cannot propagate. The feeder is unable to excite the 2nd and 3rd space leaky wave and the dominant bound wave, since their fields and the feeder field are not in conformity with each other. However, the field of the 1st higher order bound wave resembles the field of the 1st space leaky wave and can excite simultaneously. The feeder was optimized to the lowest return loss at a center frequency 3 GHz. The return losses of the antenna are shown in Fig. 4. The junction resistor between the inner conductor of the coaxial connector and the microstrip patch, losses in the substrate, in the aluminium metallization, and in the adhesive, not accounted for in the simulation process, produced worse return losses than their predicted values.

The slotline antenna with the CPW feeder, Fig. 5, has all the advantages of the uniplanar structure. The slotline was terminated by the short circuit suppressing the backward radiation and partly also the ripples in the radiation pattern. The measured and simulated antenna return losses are plotted in Fig. 6. This antenna was originally designed at 3 GHz, as was the antenna fed by the microstrip. The transition from the coaxial connector to the CPW antenna input raised the need to insert a short section of the CPW between them. This piece of line shifted the minimum of the return loss down to a frequency of 2.66 GHz.

Antenna radiation

The radiation pattern of the antenna fed by the microstrip patch is plotted in Fig. 7. The pattern was measured in the E-plane placed into the longitudinal plane of the structure symmetry. The angle Θ was taken from the forward direction. The measured pattern is a very good fit with the pattern simulated by the IE3D simulator. The ripples in the pattern and the remarkable backward radiation are due to the standing wave produced by the 1st higher order bound wave reflected back from the slotline termination. The feeder excites this wave together with the space leaky wave, as they both have a similar field distribution across the slot [4]. The standing wave is clearly visible in Fig. 3, where the current distribution map on the metalization is shown by a scale of gray color. The lowest current magnitude is shown in black

The antenna fed by the CPW patch was designed with the aim to reduce both the radiation pattern ripples and the backward radiation. The short circuited termination of the line partly eliminates the standing wave, as is documented in Fig. 5. The current flowing along the slotline edges decreases, since the leaky wave is attenuated and the standing wave has a negligible amplitude. The corresponding radiation pattern, Fig. 8, is less distorted by the ripple than the pattern in Fig. 7. Simultaneously the backward radiation is considerably reduced. The measured and simulated patterns fit well. The ripple in the radiation pattern vanished when the slotline was terminated by a semi-matched load formed by an absorber placed on both substrate surfaces on the slotline end. For comparison we also plotted the measured radiation pattern of this antenna terminated by a semi-matched load (Fig. 8). In this latter case the pattern is clearly without the ripple. The antenna beam inclined from 36.3 to 22.7 degrees from the substrate surface when the frequency changed from 2.5 to 4.0 GHz for the microstrip fed antenna, and from 58 to 42 degrees when the frequency changed from 2.35 to 3.5 GHz for the CPW fed antenna. The measured antenna gain was 7 dB at 2.66 GHz in the case of the CPW fed antenna.

Conclusions

The slotline leaky wave antenna consisting of the section of the wide slot on the thin low permittivity substrate was investigated. The presented dispersion characteristics of the 1st order space leaky leaky wave form the basis of the antenna design. Two antennas were designed, fabricated and measured. The first was fed by a microstrip patch placed on the metalless side of the substrate, and the second was fed by the CPW, which offers better parameters and a fully planar integration of the circuit and radiator. Better feeder efficiency, evaluated in terms of return loss, was achieved in comparison with [3].

The slotline antenna radiates two main beams, each on the opposite side of the substrate. Short circuited termination of the slot reduces the radiation pattern backward lobes and ripples. Frequency scanning sensitivity 7.7 deg/GHz was achieved in the 2.5-4.0 GHz range, more than seven times greater than in [3]. The measured and calculated radiation patterns compare well.

Acknowledgments

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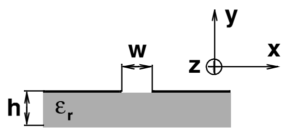

Fig. 1 Cross-section of the slotline.

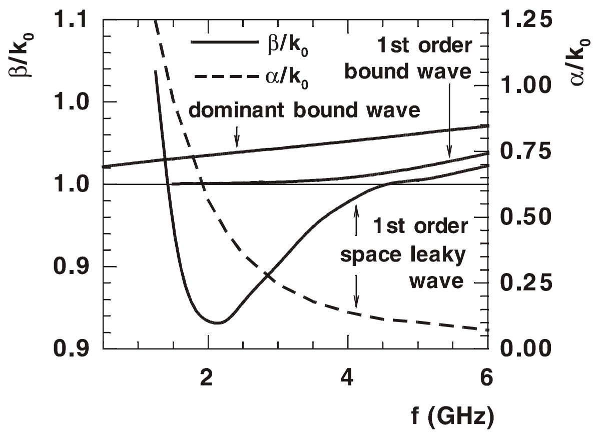

Fig. 2 Normalized phase β/k_0 and leakage α/k_0 constant of the waves on the slotline with w=60 mm, h=1.2 mm, ε_r=2.6 depending on the frequency.

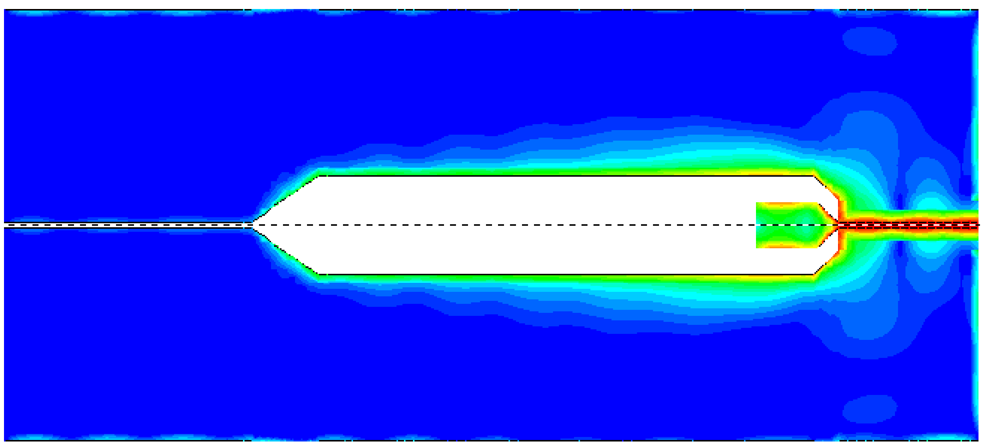

Fig 3 Layout of the antenna fed by the microstrip patch. Simulated current distribution is shown.

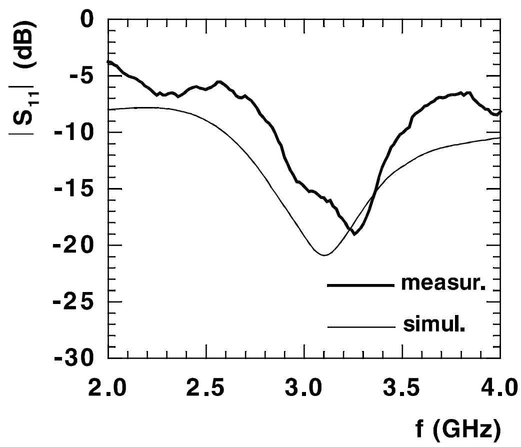

Fig. 4 Measured and calculated return loss of the antenna from Fig. 3.

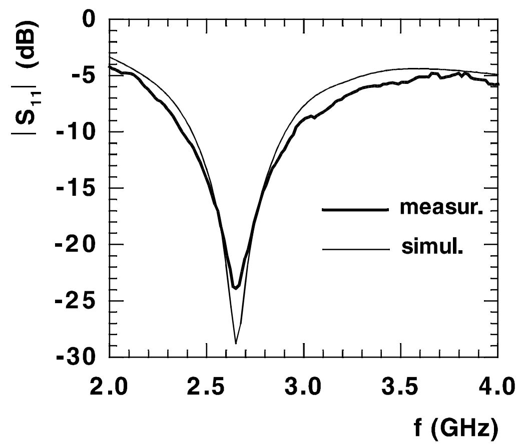

Fig. 6 Measured and calculated return loss of the antenna from Fig. 5.

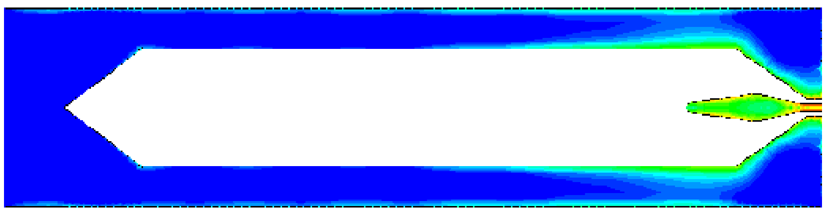

Fig 5 Layout of the antenna fed by the CPW patch. Simulated current distribution is shown.

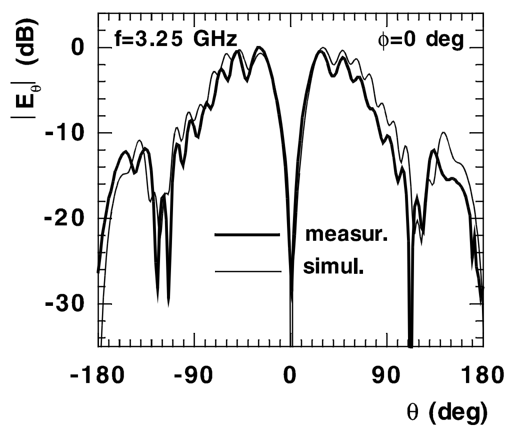

Fig. 7 Measured and calculated radiation pattern of the antenna from Fig. 3 in the E plane at 3.25 GHz.

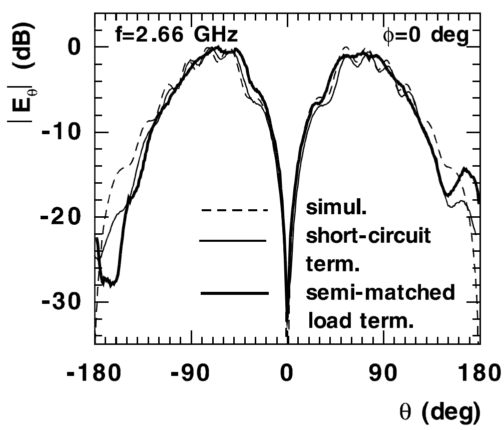

Fig. 8 Measured and calculated radiation pattern of the antenna from Fig. 4 in the E plane at 2.66 GHz with short circuited termination and when the slot is terminated by a semi-matched load.